Diamond Turned Composite Mirrors

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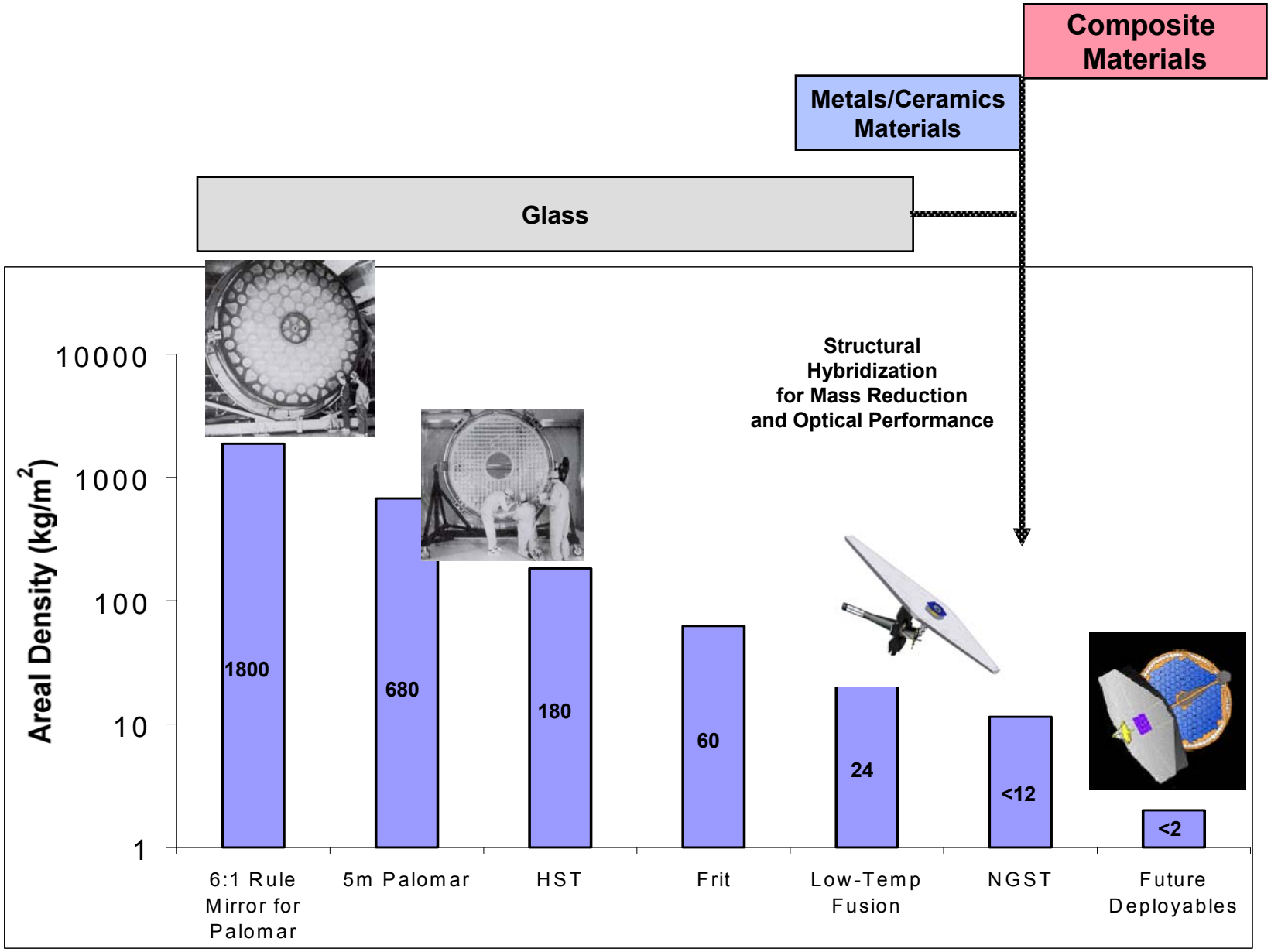
How Do Composites Fit in the Design Box?

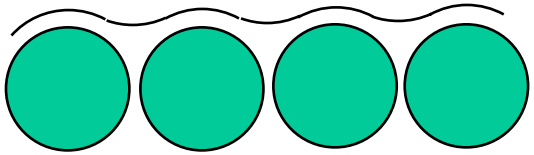
- Low Density and High Modulus
- Tailorable (Near Zero) CTE and Low Thermal Expansions In-Plane
  - Ambient and/or Cryo
- Attractive In-Plane Thermal Properties
- Low Material Cost
- Component Robustness (high Fracture Toughness)
- Processing Scalable to Very Large Sizes
- Athermal Design of Lightweight Composite Mirror w/ Dimensionally Stable Structure
- Enabling Technology for Future Large Aperture Missions

Lightweight Mirror Technology Path

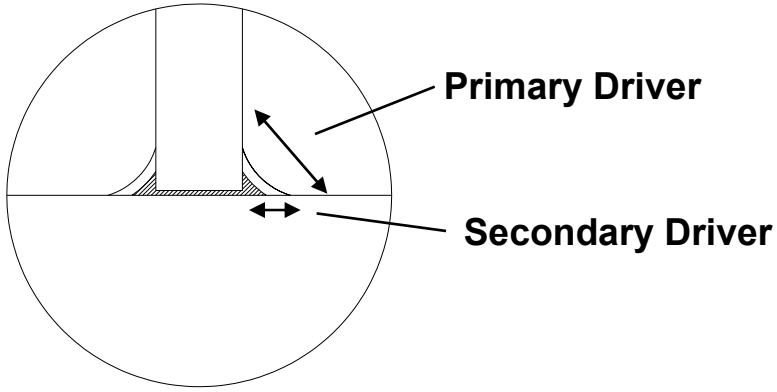


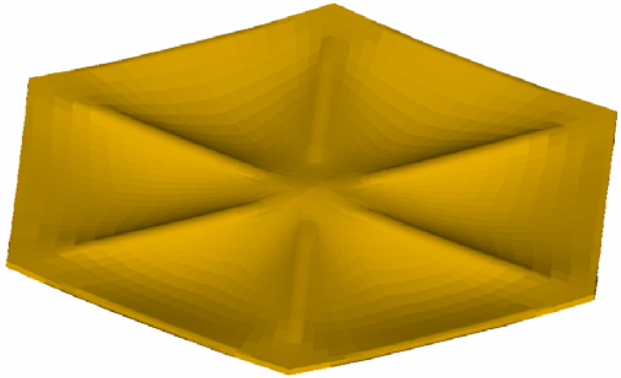
Implementation Challenges with Composites

- **Micro-Level: Diffuse Surface Effects**
  - » **Fiber Print-Thru Limits Operational Wavelength**



- **Macro Level: Bonded Construction Effects**
  - » **Rib Print-Thru Effects Mirror Figure**





New Approach: Diamond Turned Composite Mirror

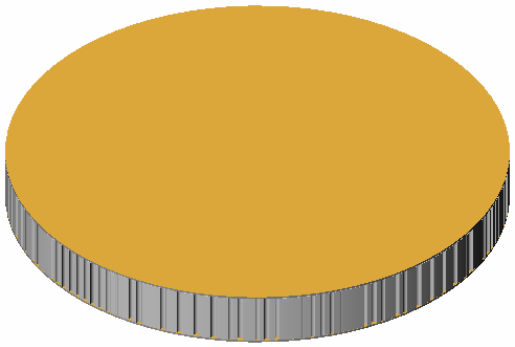
- Eliminate Fiber Print-Through By Applying a Thin Layer of Cu Plating
- Plating Is Symmetric and Tailored for Optimum Smoothness
- Two Concepts Demonstrated
  - Isogrid Sandwich Design
  - Foam Sandwich Design

NASA Phase 2 SBIR Project Overview

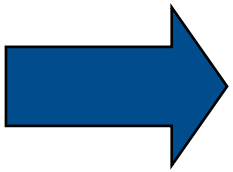
- Diamond Turned Composite
- Contract: NAS5-00227
  - Value: $599,247
  - Sponsor: NASA Goddard Space Flight Center
- Technical Objectives
  - Produce Low Areal Weight Mirror ~10 kg/m^2
  - Produce Visible Quality Surface Figure and Roughness
    - < λ/4 RMS Surface Figure Accuracy
    - < 30 Angstroms RMS Surface Roughness
  - Provide Low CTE Mirror < 1.0 ppm/˚C to Minimize Thermal Distortion

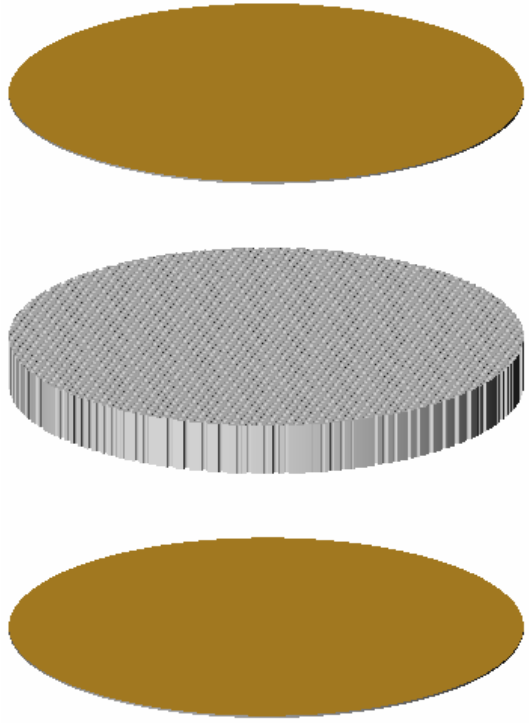
SBIR Technical Approach

- Develop/Identify Foam Material Suitable for the Application
- Develop a Copper Plating Process
- Identify Capable Diamond Turning Vendor
- Technology Demonstration



Sandwich Mirror Design



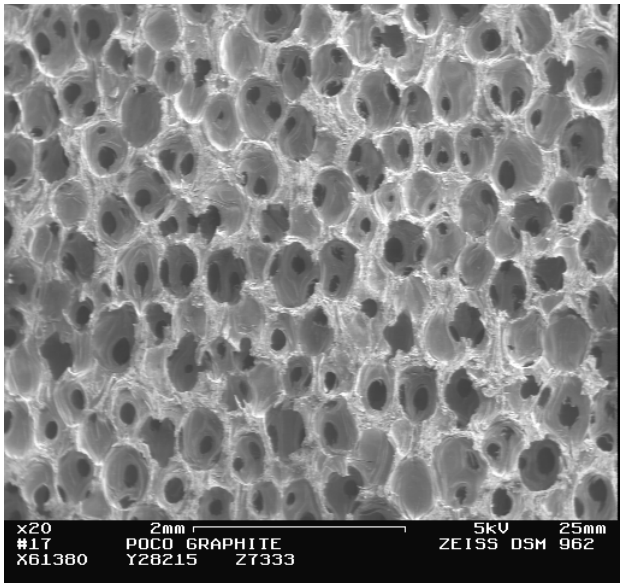


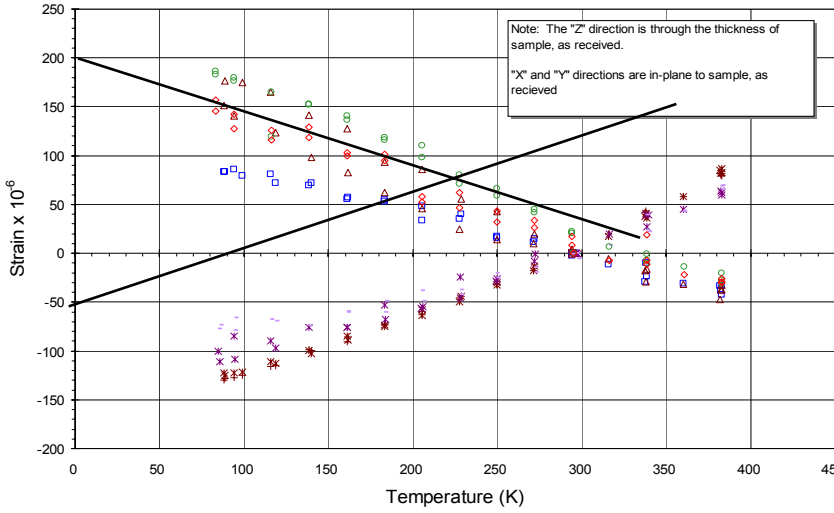
Foam Development

- Target Characteristics
  - Low Density (< 10 pcf or 0.16 g/cc)
  - Low CTE (< 0.5 ppm/F or 0.9 ppm/C)
  - Reasonable Thermal Conductivity (> 10 Watts/m-K)
  - Uniform and Consistent Properties (Mainly Modulus & CTE)
- No Existing Foam Readily Meets These Requirements
- Development Effort Focused on Tailoring Two Existing Foams
  - AETB Foam
  - Poco Graphite Foam

Foam Development
Poco Graphite Foam

- **Background**
  - **High Thermal Conductivity**
    - **In-Plane: 90 W/m-k**
    - **Thru-Thickness: 245 W/m-k**
  - **Low CTE**
    - **In-plane: 0.6 ppm/˚C**
    - **Thru-Thickness: -0.6 ppm/˚C**
  - **Planar Isotropy**
- **Challenges**
  - **Heavy (0.55 g/cc)**
  - **Friable**
- **Development**
  - **Lightweighting Concepts**
  - **Bonding Process**
  - **Foam Cell Coating**
- **Results: Developed a Foam Material with All Target Characteristics**





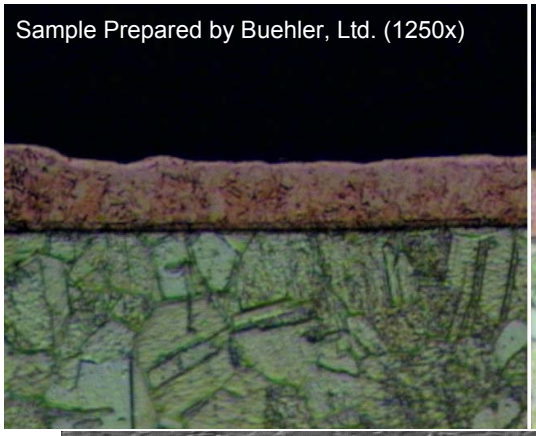
Plating Development

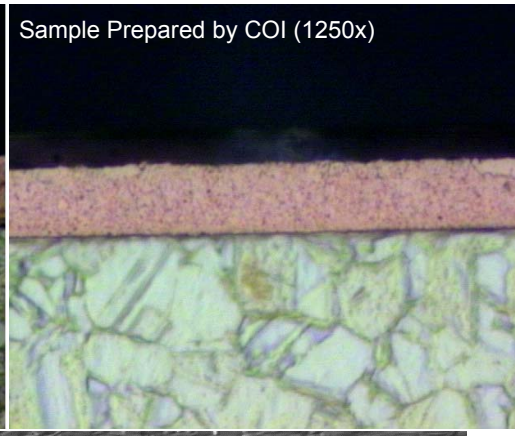
- Target Plating Characteristics
  - Compatibility with CFRP Substrates
  - Very Low Grain Size (Sub-Micron)
  - Tailorable & Uniform Thickness
- Leverage COI's Heritage with Plating on Composites
- Development Effort Focused on
  - Grain Size Refinement
  - Low Stress Plating
  - Good Adhesion

Plating Development

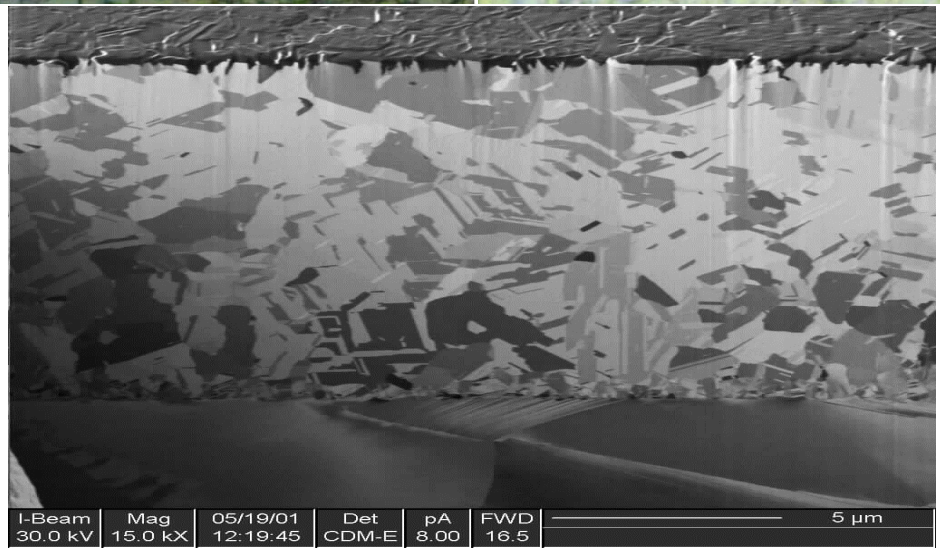
Grain Size Refinement

- **Systematic Optimization of Process Parameters (DOE's)**
  - » **Bath Temp**
  - » **Current Density**
  - » **Brightener %**
  - » **Anode/Cathode Ratio**

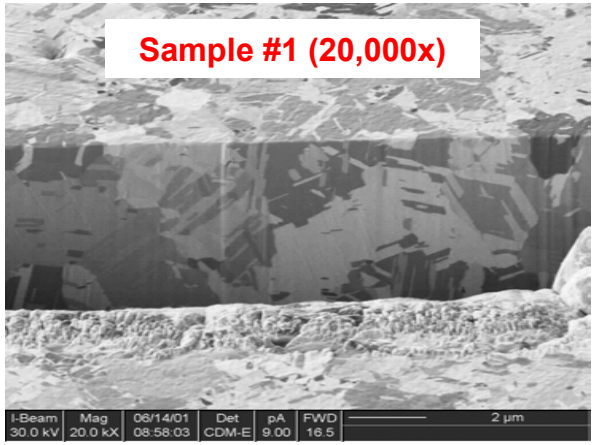


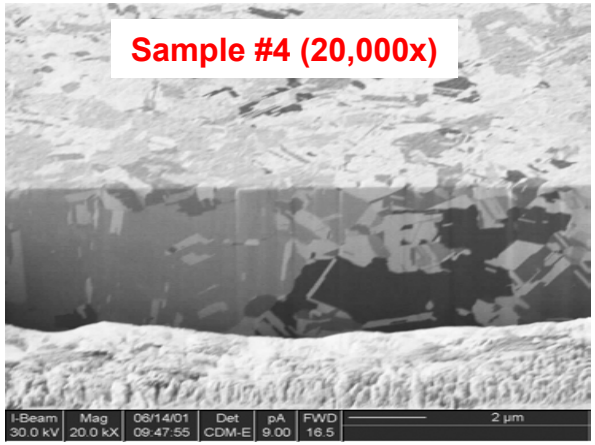


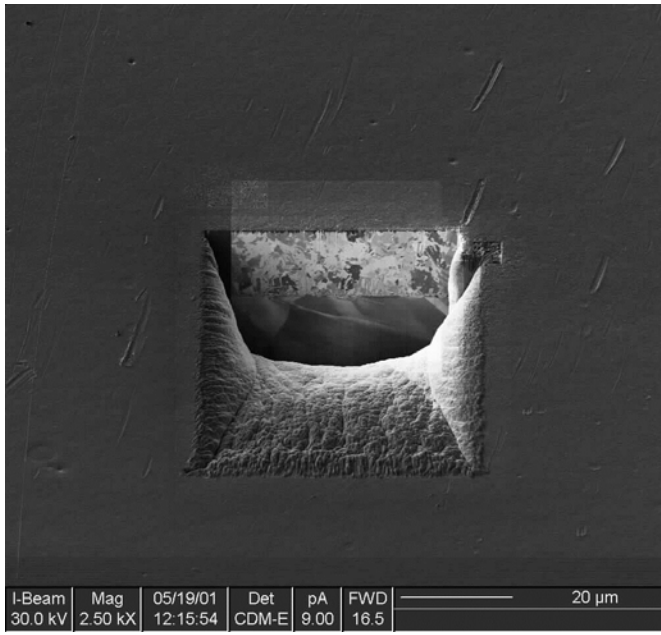
- **High Quality Plating Achieved**
  - » **0.3 - 0.5 Microns Average**
  - » **Uniform Thickness**
  - » **Good Adhesion to Substrate**

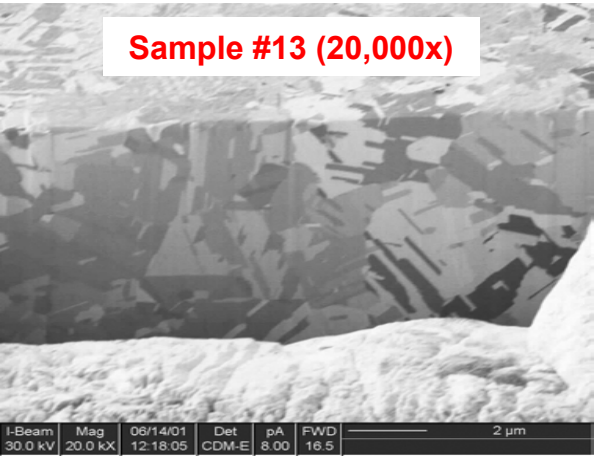


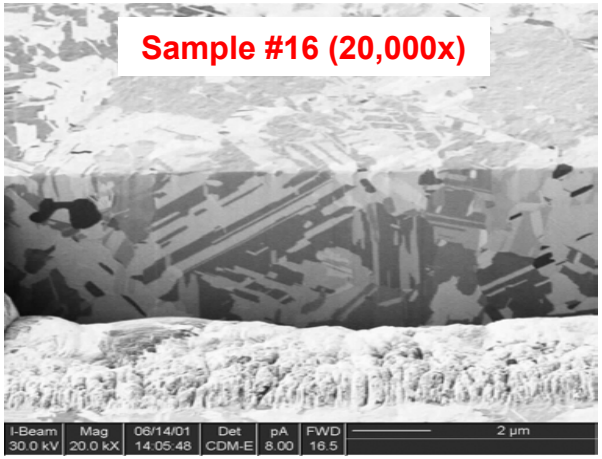
Grain Size
FIB Images









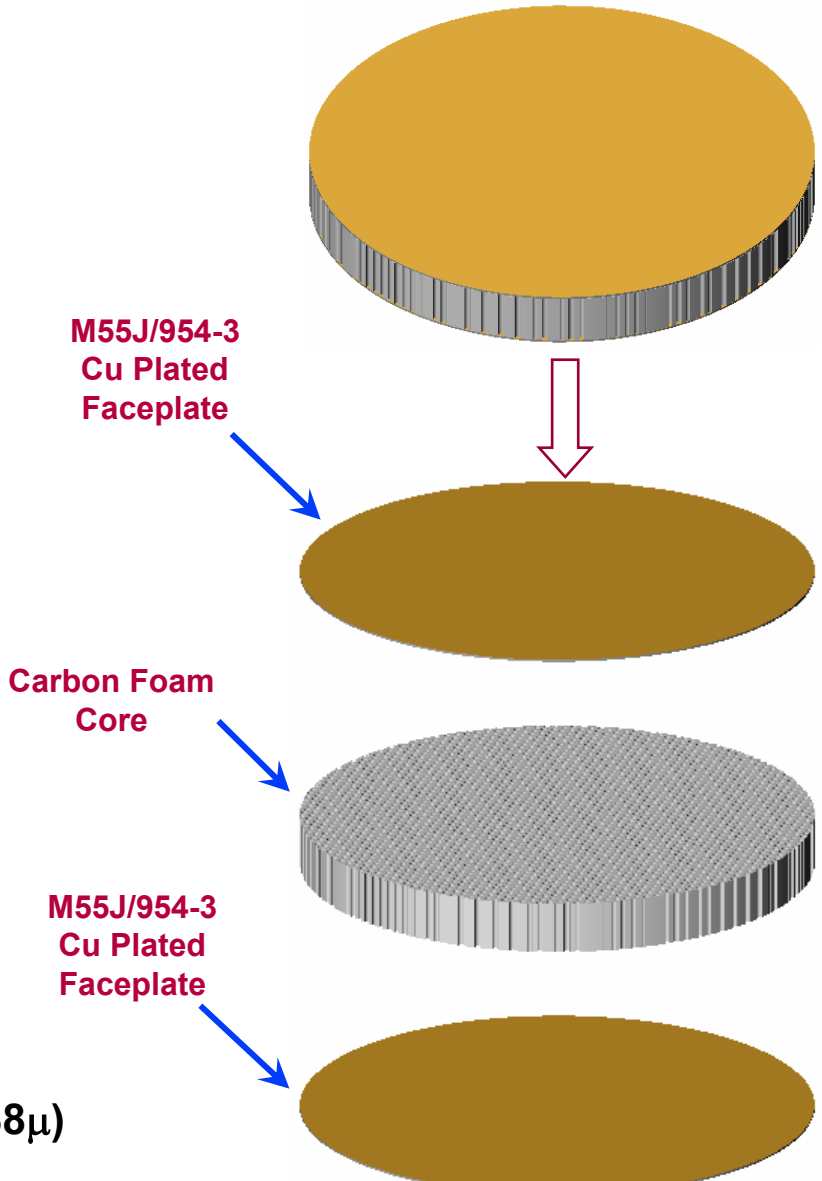


Technology Demonstration

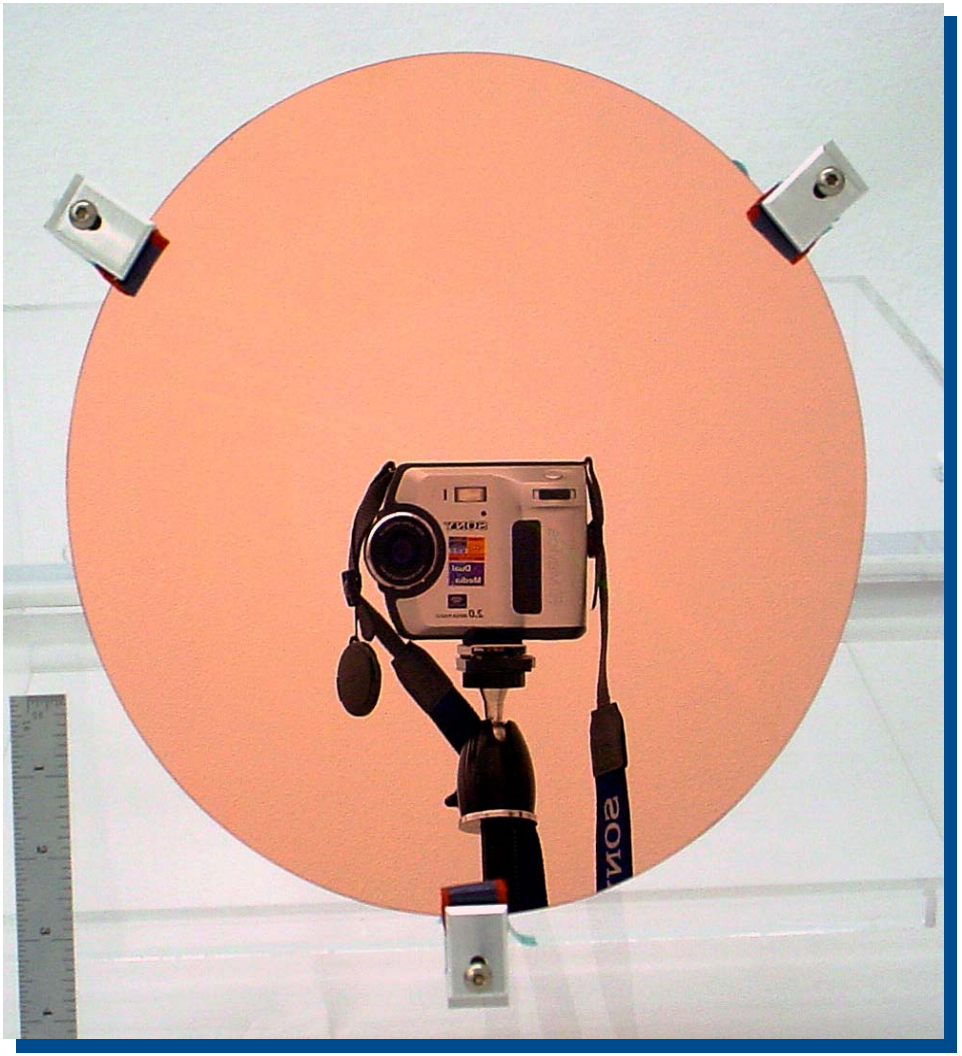
- Three Small Mirrors (5” Diameter) for Process Development Purposes
- One Demonstration Mirror (10” Diameter) with Foam Core
- One Demonstration Mirror (8” Diameter) with Isogrid Core

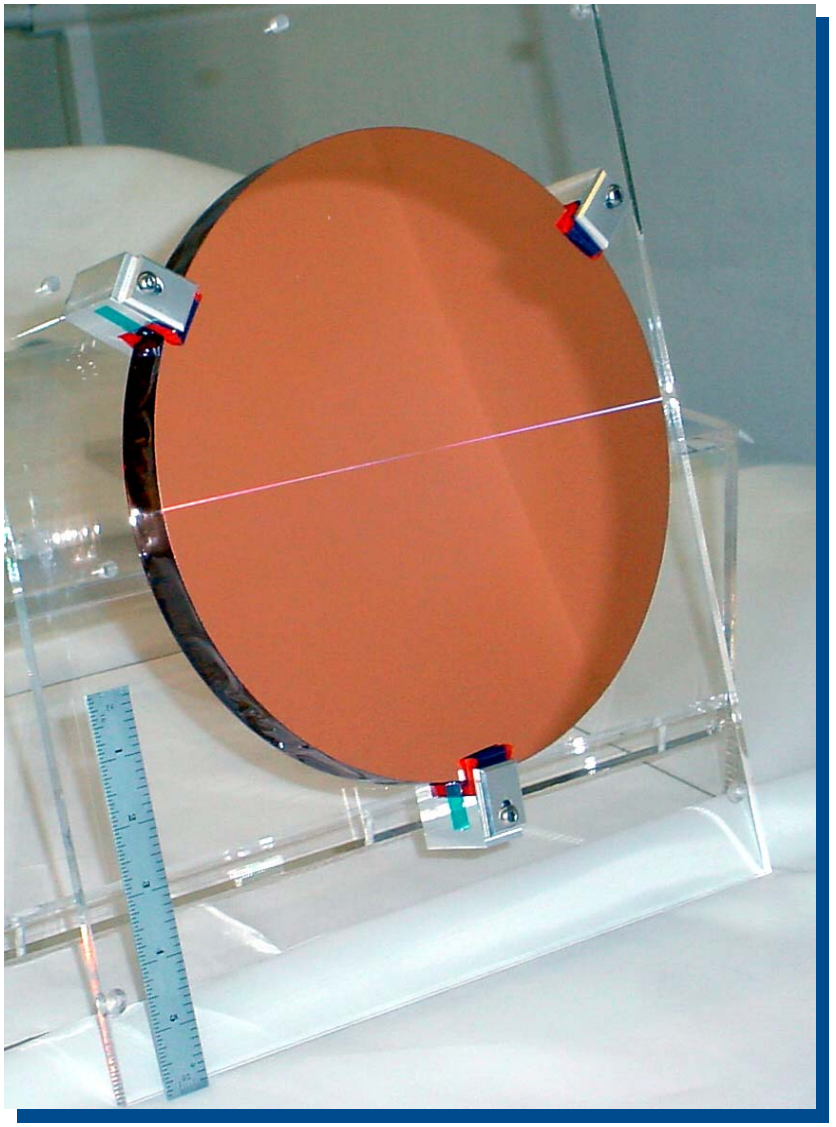
Technology Demonstration
250mm Foam Core Mirror

- **Mirror Design Features**
  - Low Areal Density 12 kg/m^2 Demonstrated on ∅250mm Aperture
  - Copper Plated Facesheet (0.002” Cu Plating Thickness)
  - Low CTE Composite Facesheets (CTE < 0.1 ppm/°C)
  - Low CTE Carbon Foam Core (CTE = 0.6 ppm/°C)
  - High Thermal Conductivity Core (245 W/m*K Out-of-Plane)
  - Robust Lightweighted Core Design for Optimized Optical Processing
- **Key Technology Demonstration**
  - Diamond Turning Performed by NASA Marshall Space Flight Center
  - 20 - 25 Å Surface Roughness
  - 1/3 λ RMS Surface Figure Accuracy (λ = 0.6238μ)



0.25m Foam Mirror Demonstrator

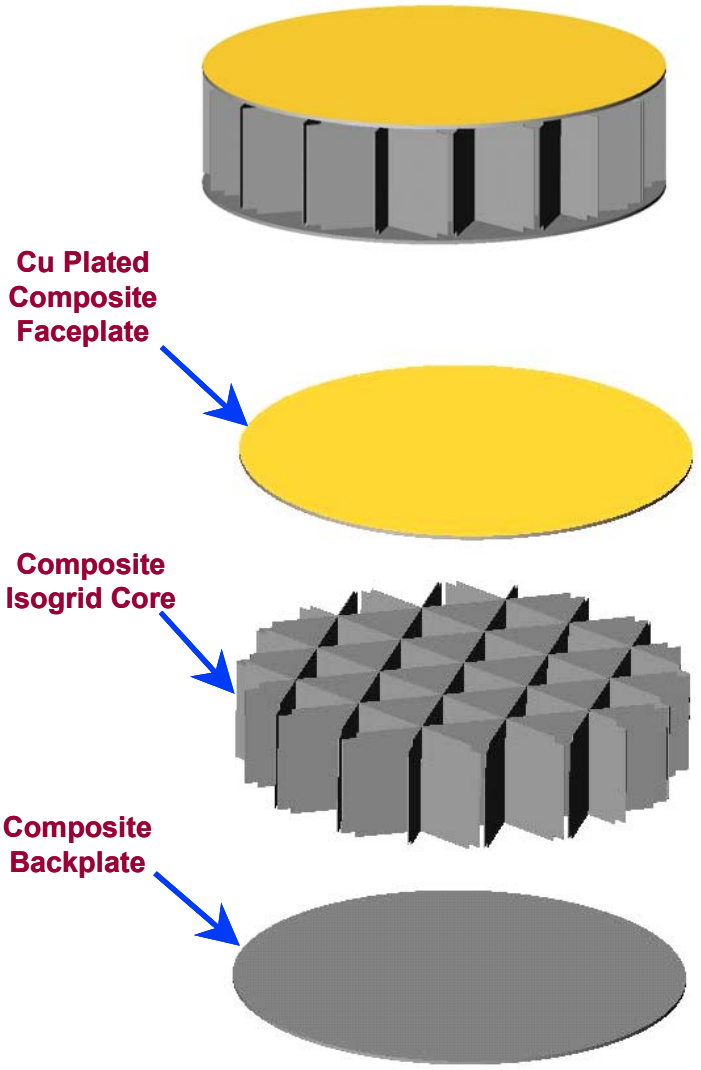




Technology Demonstration

200 mm Isogrid Core Mirror

- **Key Mirror Design Features**
  - » 200mm Aperture at 9 kg/m^2 Areal Density
  - » Copper Plated Facesheet (0.076mm Cu Plating Thickness)
  - » Low CTE Composites < 0.1 ppm/°C
  - » Low CTE Composite Isogrid Core < 1.5 ppm/°C
  - » High Stiffness Lightweight Open Cell Core Design to Optimize Mechanical Performance
- **Technologies Demonstrated**
  - » Diamond Turning Performed @ NASA Marshall Space Flight Center
  - » 30 Å Average Surface Roughness
  - » 0.6 micron RMS Surface Figure



SUMMARY

- Plated-and-Diamond-Turned Composite Facesheet Approach Demonstrated
- Demonstrator Mirrors Achieved Significant Results
  - Areal Density < 10 kg/m2
  - Roughness < 30 Å
  - Figure < 1/3 λ RMS
- Advantages of Diamond Turned Composite Mirror
  - Eliminates Fiber Print-thru and Moisture Instability Typically Associated with Composite Mirror Approaches
  - Scalable to Large Aperture, Aspheric
  - Low Cost Fab and Processing